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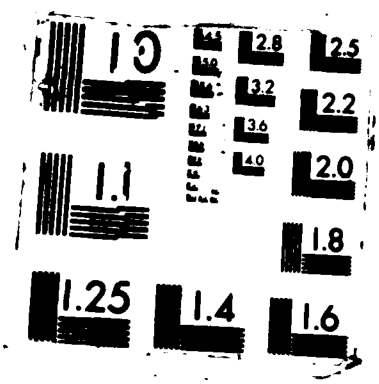
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1.8
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INTERPLANETARY PROTONS ($E_p \approx 1$ MEV)

1973-1986 AND OUT TO 22.4 AU

by

J. A. Van Allen

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Department of Physics and Astronomy

THE UNIVERSITY OF IOWA

Iowa City, Iowa 52242

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Department of Physics and Astronomy
The University of Iowa
Iowa City, Iowa 52242

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ABSTRACT

This paper uses a homogeneous body of data on mean annual values N of the interplanetary intensity of protons ($0.61 < E_p < 3.41$ MeV) in the period 1973-1986 and over the heliocentric radial distance range $1.0 < r < 22.4$ AU. It is found that the quantity Nr^2 is well correlated with the annual mean sunspot number, with the exception of anomalously low values in 1979, 1980 (in particular), and 1981. The anomaly is attributed to a gross change in the interplanetary magnetic field associated with reversal of the polarity of the sun's polar field.

Introduction

A homogeneous body of data on the intensity of low energy protons ($0.61 < E_p < 3.41$ MeV) in the interplanetary medium has been accumulated on an effectively continuous basis since early 1973 by the University of Iowa instrument on Pioneer 11. This Ames Research Center/NASA spacecraft has moved outwards in approximately the ecliptic plane from a heliocentric radial distance of 1 AU on 6 April 1973 to 22.4 AU at the end of 1986. The presently available observations span solar sunspot cycle 21 and include the epoch of reversal of the sun's polar magnetic field around 1980.

A catalog of 265 distinct proton events has been compiled in graphical and tabular form [Van Allen, 1987]. Experimental details are included in the referenced report.

The present paper is a preliminary attempt to separate the radial dependence from the solar activity dependence of the integrated intensity of interplanetary protons. All types of proton events are treated on an equal footing without discrimination as to their nature.

The Data

Figures 1, 2, 3, and 4 illustrate raw daily mean counting rates of our proton detector on Pioneer 11 as a composite function of time and radial distance r. These figures are samples from the full set of fourteen in the previously referenced report. The raw counting rate includes a "background" rate of 0.062 c s^{-1} provided by an end-to-end calibration source of alpha particles (Am^{241}). The absolute, spin-averaged unidirectional intensity j of protons ($0.61 < E_p < 3.41$ MeV) is given by $j = 22.7 (N' - 0.062)$ wherein N' is the raw counting rate in c s^{-1} and j is in $(cm^2\ s\ sr)^{-1}$. The net counting rate $N = (N' - 0.062)$.

Analysis

Figure 5 shows annual mean values of N for 1973-1986 together with annual mean sunspot numbers. It is obvious that N depends importantly on r.

In an attempt to learn the dependence of N on r, I have tried the simple assumption that, for a given level of solar activity, N varies as $r^{-\alpha}$, with trial values $\alpha = 1, 1.5, 2$, and 3. The results are shown in Figures 6,7, 8, and 9, which are plots of annual mean values of Nr^{α} vs. time. The best value of α is presumed to be the one that causes the Nr^{α} vs. time curve to most nearly resemble the arbitrarily normalized time dependence of sunspot number.

I judge that the best value of α is about 2.

For any value of α there is, in this simple scheme, an unavoidable anomaly represented by the low values of Nr^{α} for 1979, 1980, and 1981 and especially for 1980. The time-association of this anomaly with the reversal of the polarity of the sun's polar magnetic field [Makarov et al., 1983; Webb et al., 1984; DeVore and Sheeley, 1987; Smith and Thomas, 1986] is noteworthy.

Discussion

The most relevant previous study of this general nature is that of Van Hollebeke et al. [1978]. These authors studied the radial dependence of the maximum proton ($0.9 < E_p < 2.2$ MeV) intensity in individually correlated corotating particle streams in the radial range 0.3 to 10 AU, using 1 AU data for normalization. They found a strongly positive radial gradient of normalized maximum intensity in the range 0.3 to 1.0 AU, an indeterminate dependence on r in the range 1.0 to 4.0 and a strongly negative gradient in the range 4.0 to 10 AU [Figure 5 of Van Hollebeke et al.]. Ignoring the range $r < 1.0$ AU, for which I have no data, I judge that their results are not in clear disagreement with my findings herein for $r > 1.0$ AU. It should be noted that Van Hollebeke et al. plot the ratio of maximum intensity in individual corotating streams at different values of r whereas I use mean annual intensities. Hence the two studies are not strictly comparable.

Virtually all interplanetary proton events (including corotating ones) are associated with shocks and other magnetic discontinuities. It therefore appears that local acceleration of ambient "seed"

particles of lower energy [Pesses et al., 1982; Decker and Vlahos, 1986] is the dominant cause of 1 MeV proton events. The average population of seed particles might be expected to diminish monotonically with increasing radial distance. The other factors in determining the gross dependence of N on r are (a) the topology of the interplanetary magnetic field and (b) the incidence and intensity of magnetic discontinuities. The anomalously low values of Nr^{α} near the time of maximum sunspot number are apparently the result of a gross change in factors (a) and/or (b) during the reversal of polarity of the sun' polar field, centered on 1980. A more detailed study is in progress.

Conclusion

The tentative conclusion of this exploratory study is that the annual mean intensity N of interplanetary protons ($0.61 < E_p < 3.41$ MeV) is, with the exception of anomalously low values during 1979, 1980, and 1981, well correlated with the annual mean sunspot number if N varies with heliocentric radial distance r as r^{-2}. The "1980 anomaly" is attributed to the reversal of the polarity of the sun's polar magnetic field and a consequent three-year transient in the gross topology of the interplanetary magnetic field and/or the incidence of magnetic discontinuities.

Acknowledgments

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Solar-Geophysical Data, p. 11, Number 512, Part I, National Oceanic and Atmospheric Administration, Boulder, CO, April 1987.

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Webb, D. F., J. M. Davis, and P. S. McIntosh, Observations of the reappearance of polar coronal holes and the reversal of the polar magnetic field, Solar Physics, 92, 109-132, 1984.

FIGURE CAPTIONS

Fig. 1. A plot of the raw daily mean counting rate N' of detector G on Pioneer 11 as a function of day of the year (DOY) 1974. The raw rate includes 0.062 c s^{-1} due to a fixed calibration source. The heliocentric radial distance r is shown at the top of the graph.

Fig. 2. Same as Figure 1, except for 1980.

Fig. 3. Same as Figure 1, except for 1982.

Fig. 4. Same as Figure 1, except for 1985.

Fig. 5. A plot of the net annual mean counting rate N = (N' - 0.062) of detector G on Pioneer 11 (solid line) vs. year. The solid circles are annual mean sunspot numbers [Solar Geophysical Data, 1987]. The respective vertical scales are arbitrarily chosen for graphical clarity.

Fig. 6. A plot of Nr vs. year. Otherwise similar to Figure 5.

Fig. 7. A plot of $Nr^{1.5}$ vs. year. Otherwise similar to Figure 5.

Fig. 8. A plot of Nr^2 vs. year. Otherwise similar to Figure 5.

Fig. 9. A plot of Nr^3 vs. year. Otherwise similar to Figure 5.

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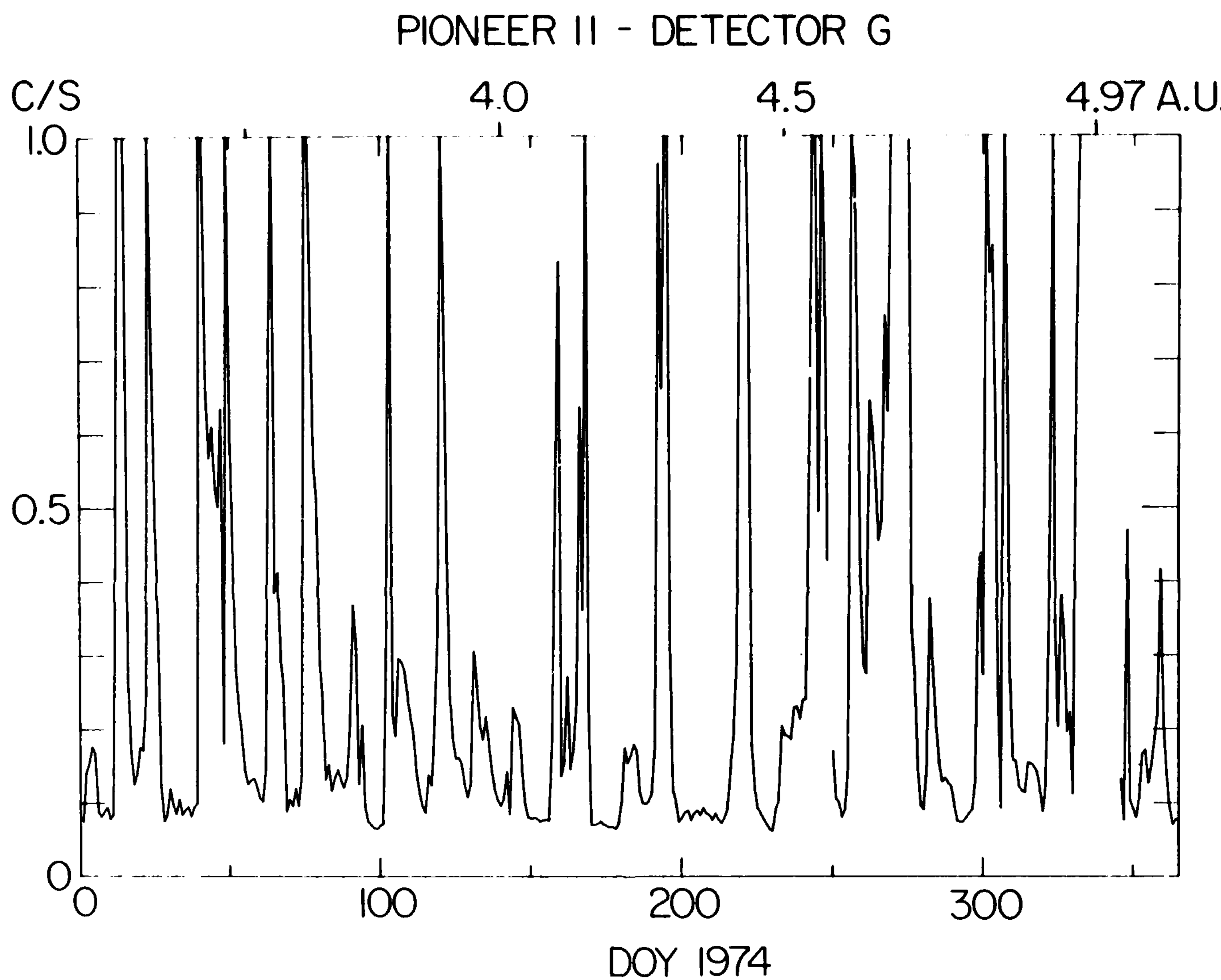

Figure 1

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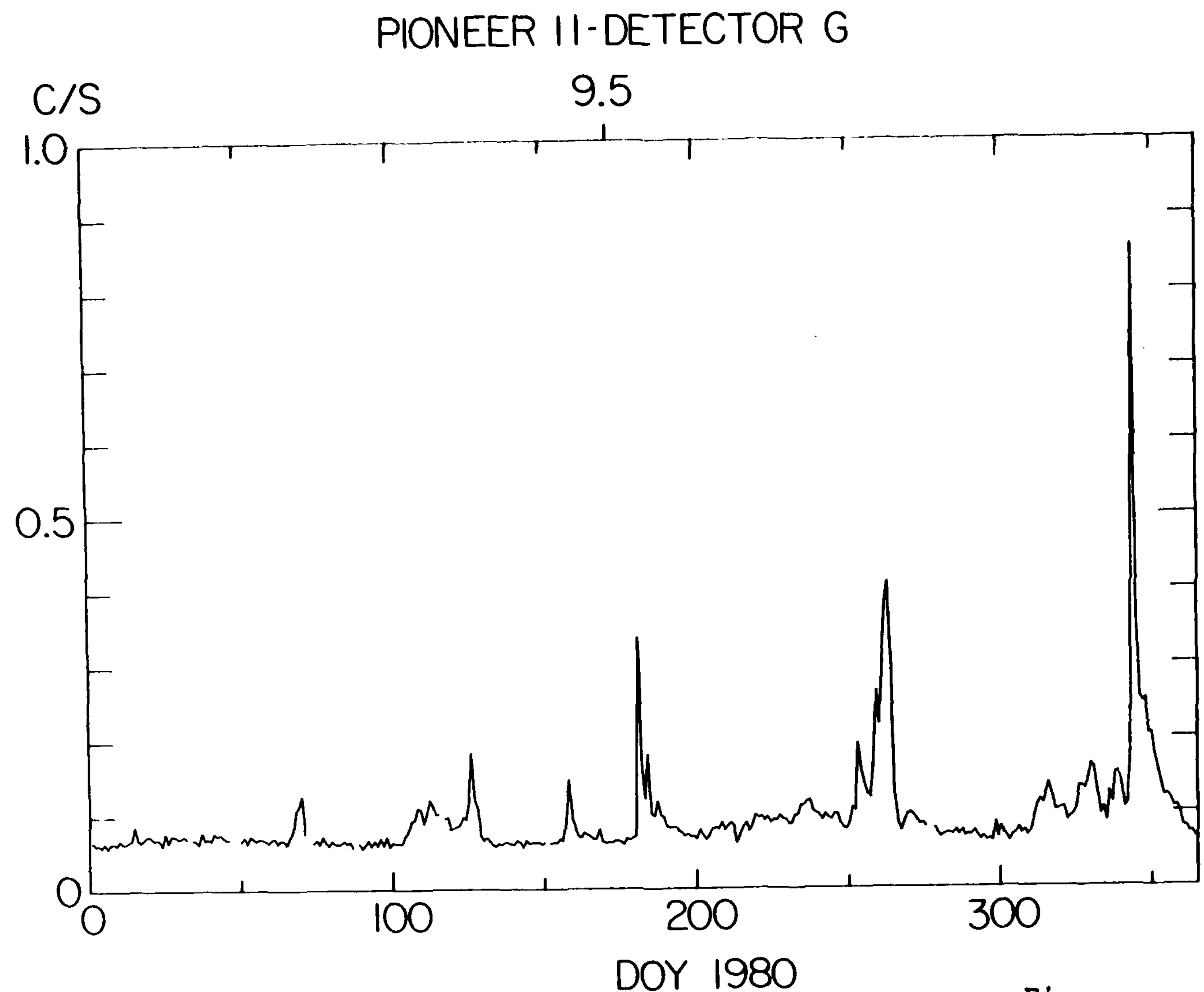

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C-G87-208

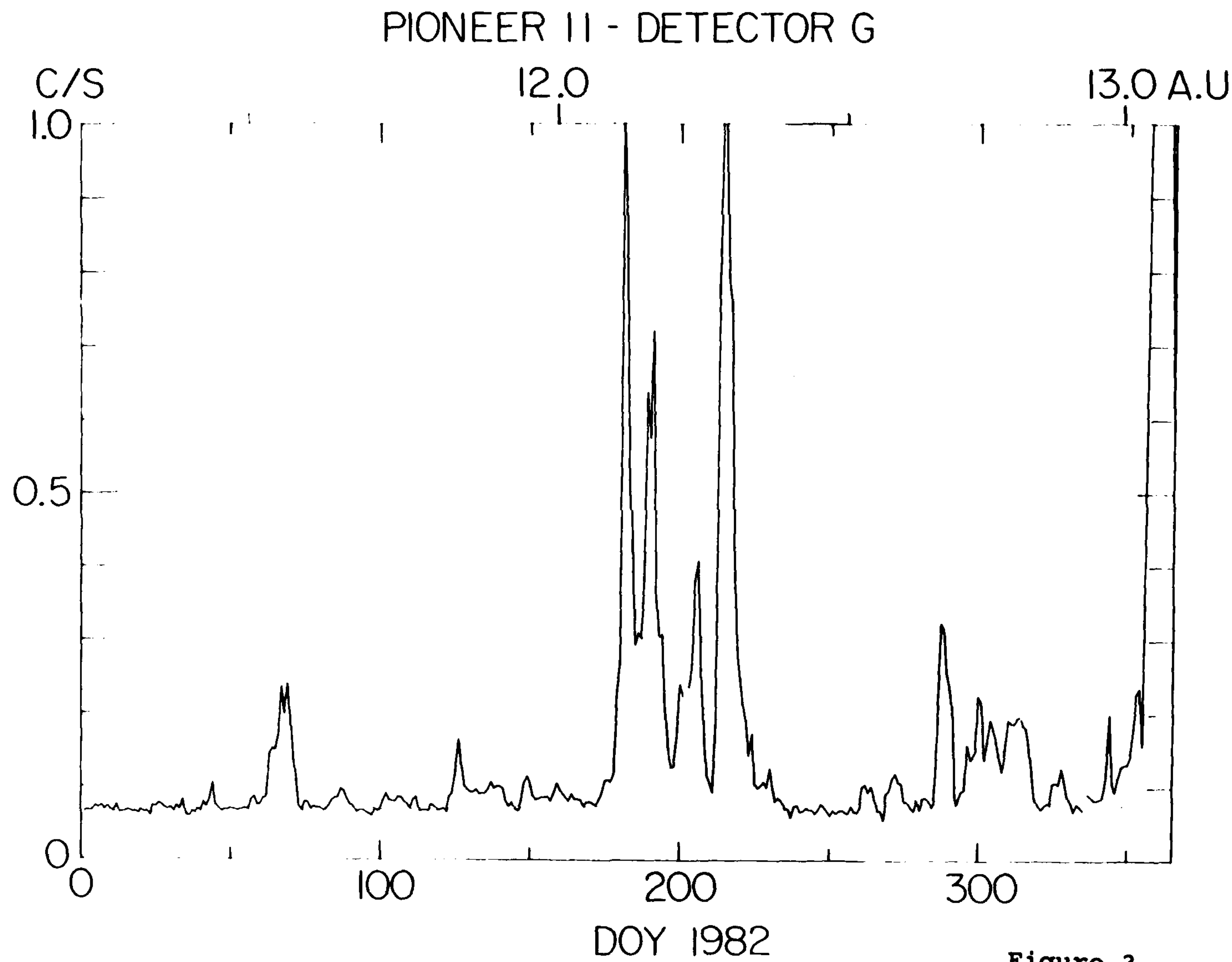


Figure 3

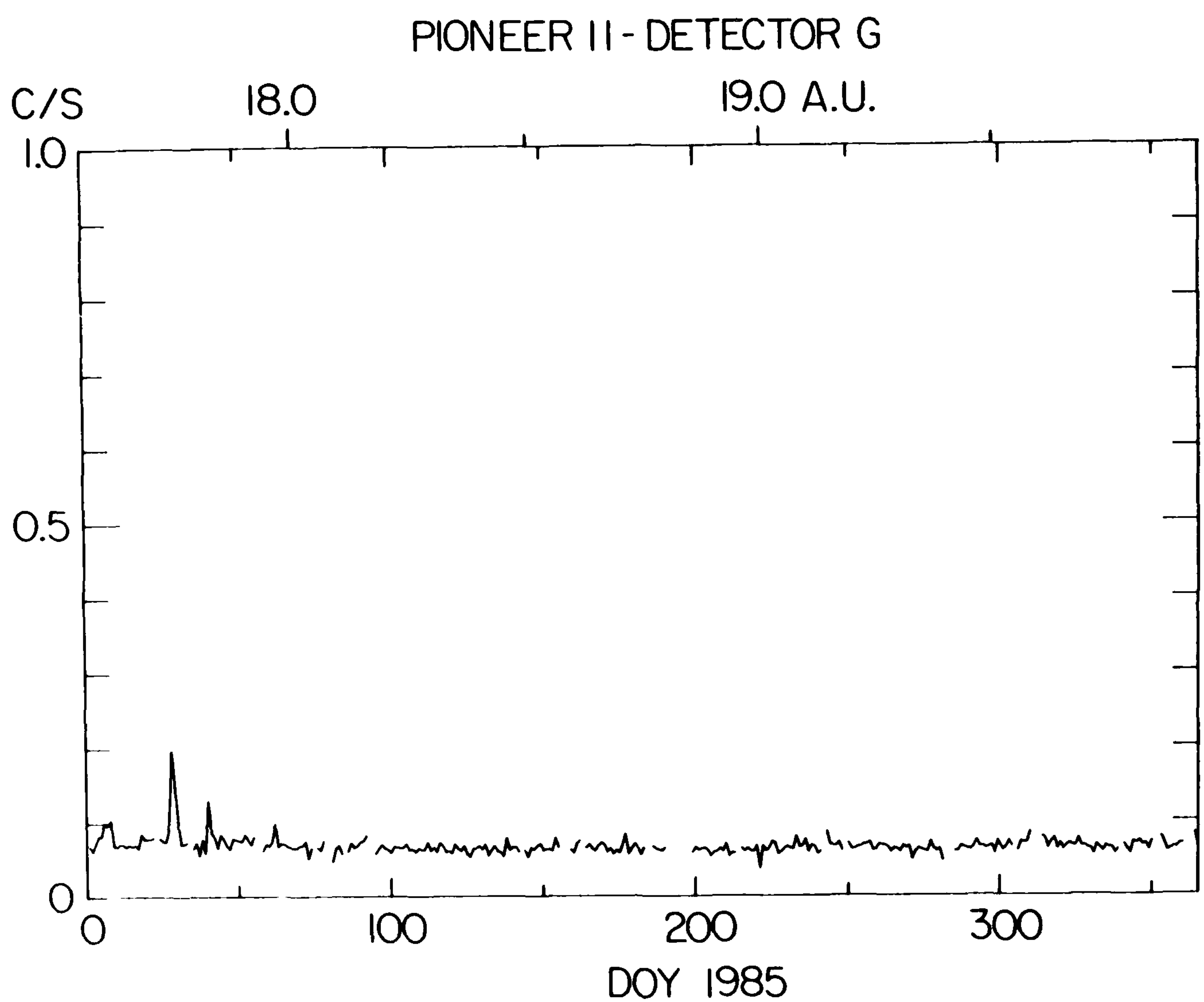
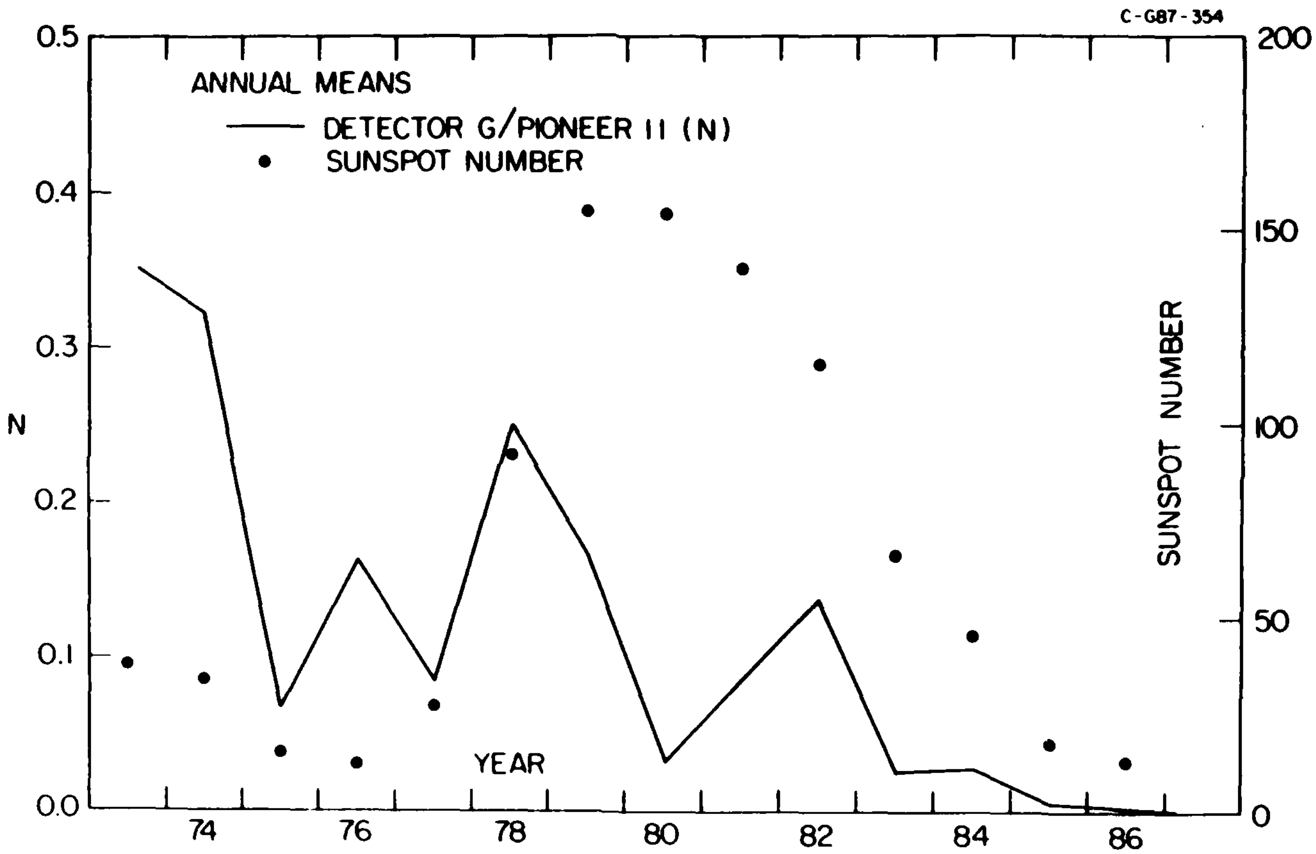

PIONEER 11 - DETECTOR G
C/S
18.0
19.0 A.U.
1.0
0.5
0
0
100
200
300
DOY 1985

Figure 4



C-G87-354
ANNUAL MEANS
DETECTOR G/PIONEER II (N)
SUNSPOT NUMBER
N
0.5
0.4
0.3
0.2
0.1
0.0
200
150
100
50
0
SUNSPOT NUMBER
YEAR
74
76
78
80
82
84
86

Figure 5

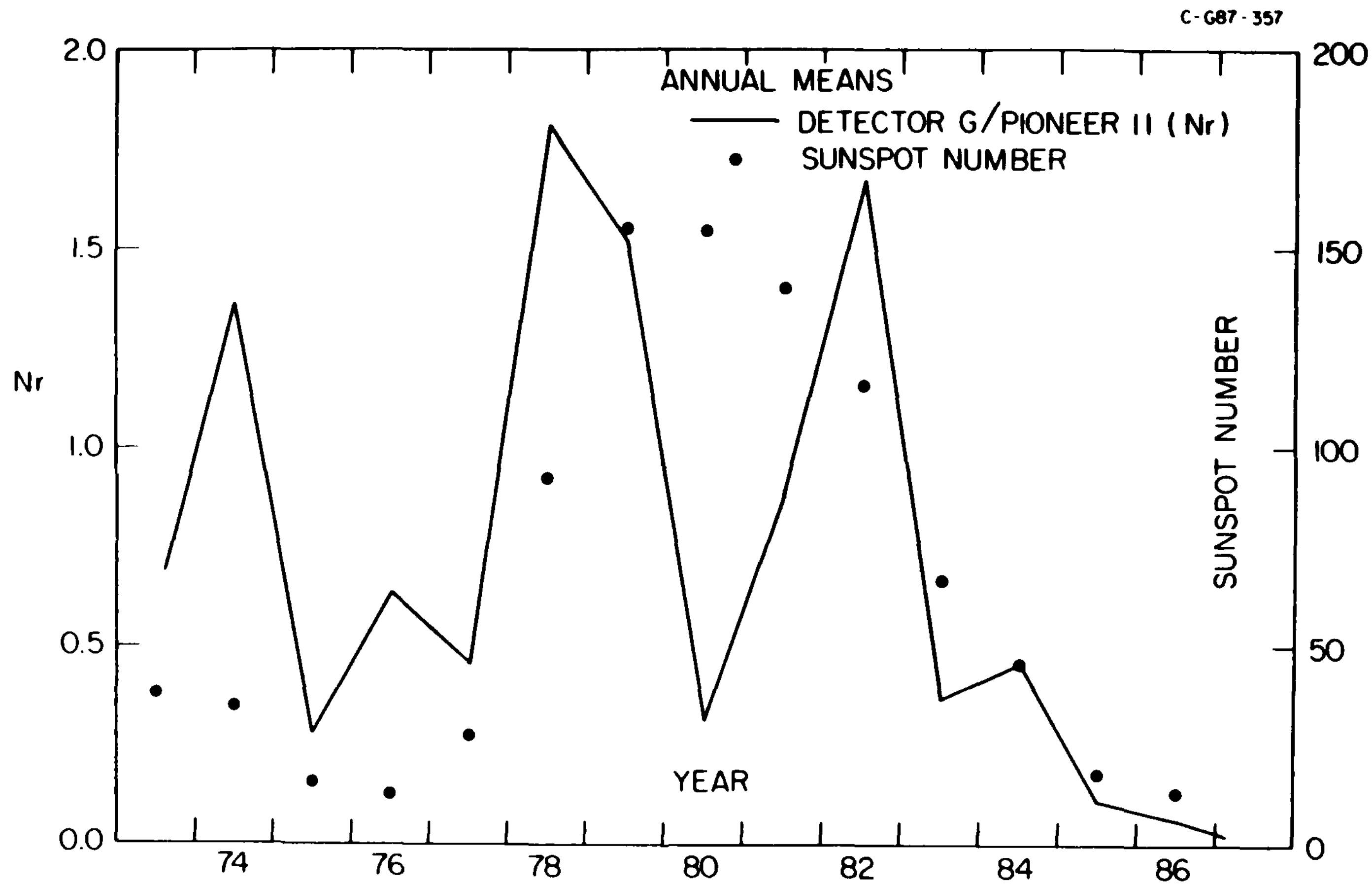

C-G87-357
ANNUAL MEANS
DETECTOR G/PIONEER II (Nr)
SUNSPOT NUMBER
Nr
2.0
1.5
1.0
0.5
0.0
200
150
100
50
0
SUNSPOT NUMBER
74
76
78
80
82
84
86
YEAR

Figure 6

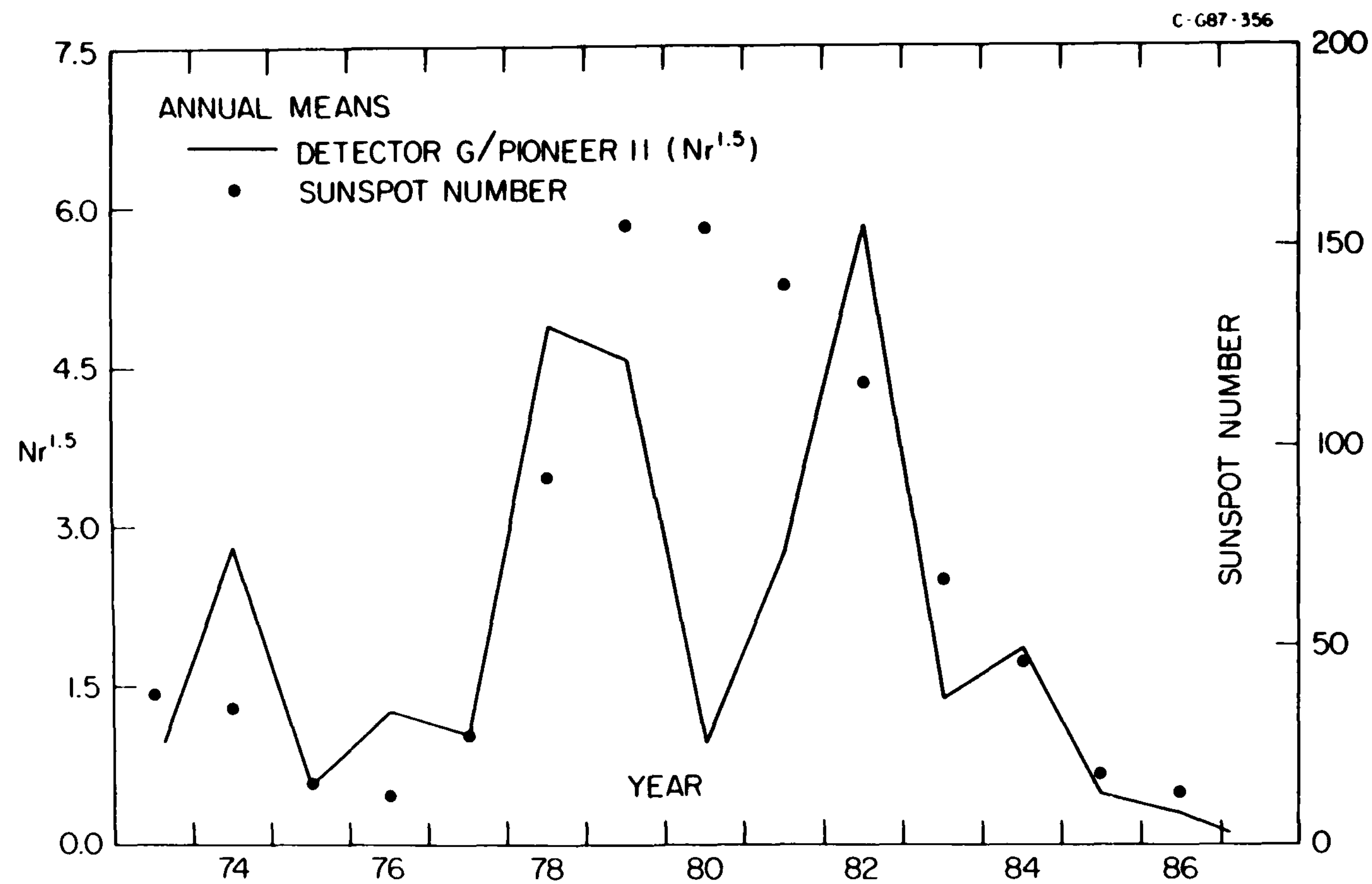

C-G87-356
ANNUAL MEANS
DETECTOR G/PIONEER II ($Nr^{1.5}$)
SUNSPOT NUMBER
$Nr^{1.5}$
7.5
6.0
4.5
3.0
1.5
0.0
74
76
78
80
82
84
86
YEAR
SUNSPOT NUMBER
200
150
100
50
0

Figure 7

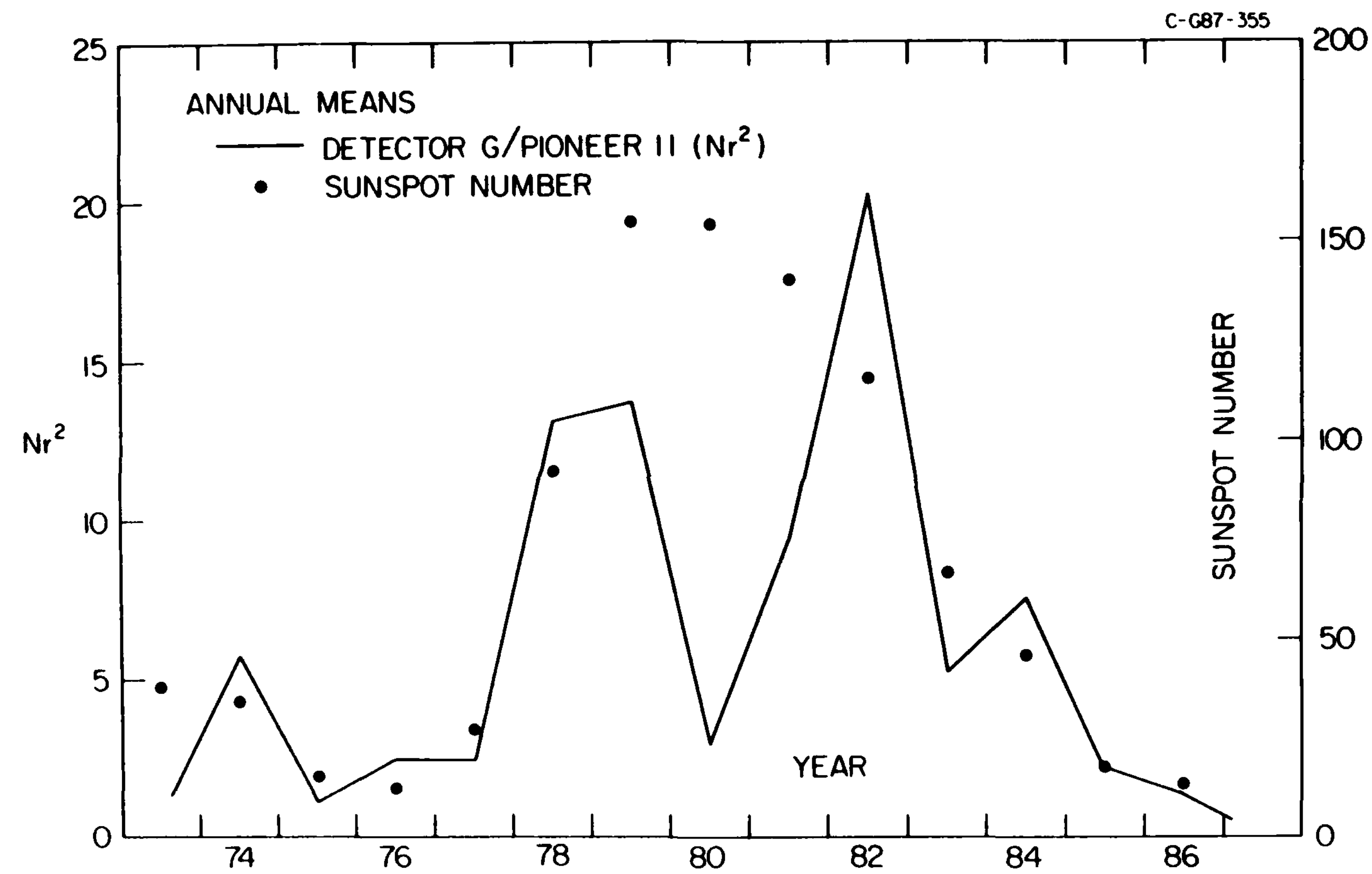

C-G87-355
ANNUAL MEANS
DETECTOR G/PIONEER II (Nr²)
SUNSPOT NUMBER
Nr²
25
20
15
10
5
0
200
150
100
50
0
SUNSPOT NUMBER
74
76
78
80
82
84
86
YEAR

Figure 8

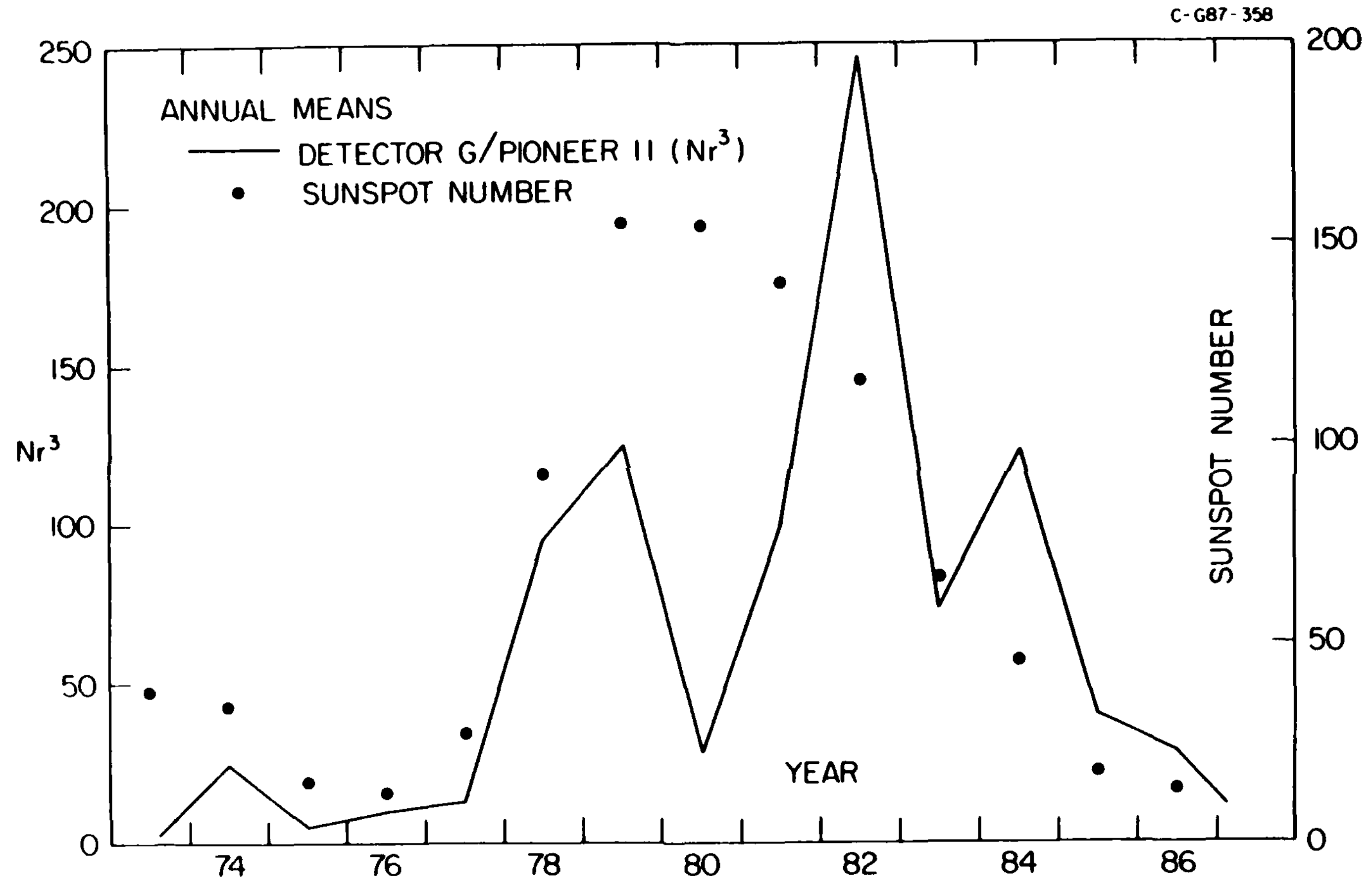

C-G87-358
ANNUAL MEANS
DETECTOR G/PIONEER II (Nr³)
SUNSPOT NUMBER
Nr³
250
200
150
100
50
0
74
76
78
80
82
84
86
YEAR
SUNSPOT NUMBER

Figure 9

END
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